In-Flight Wing Deformation Measurements on a Glider

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ABSTRACT
Flight testing is both vital in terms of collecting data for aeronautic research and at the same time fascinating for its contributors. Taking a glider as a versatile test bed example, this paper presents a transnational measurement campaign within the framework of a collaborative project funded by the European Commission. This project Advanced In-Flight Measurement Techniques 2 (AIM²) is a follow-up of Advanced In-Flight Measurement Techniques (AIM) and dedicated to developing and enhancing promising optical metrology for various flight test applications up to an industrial level.
The Image Pattern Correlation Technique (IPCT) and the Infrared Thermography (IRT) are two of these modern non-intrusive measurement methods that were further developed and applied to the glider test bed within the scope of AIM². Focusing on optical deformation measurements with IPCT the experimental setup, the flight testing and results are summarily discussed. Gliders are no commonly used flight test platforms. That is why this contribution is topped off with some lessons learned in general and especially related to the presented application. The experience to be shared with the flight testing community addresses equipment preparation, data collection and processing as well as how to meet official requirements and perform test flight operations in a dense controlled airspace.

NOMENCLATURE

AIM	Advanced In-Flight Measurement Techniques
AIM²	Advanced In-Flight Measurement Techniques 2
ARC	Airworthiness Certificate
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.
DMU	Digital Mock-Up
EASA	European Aviation Safety Agency
FCL	Flight Crew Licensing
FEM	Finite Element Method
IPCT	Image Pattern Correlation Technique
PIV	Particle Image Velocimetry

1.0 INTRODUCTION

Since decades aircraft design is divided into fixed, well established phases and development steps. They still stand the time passing by with continuous advancement of tools. For example intense flight testing of all new aircraft models is of major importance. However, to keep up with the time the goals, scope and methodology have changed a lot although the general purpose of airworthiness approval is indispensable(1). Contemporary design processes are strictly connected with economic factors such as environmental awareness, fuel efficiency and durability of the airframe as well as shareholders benefits. Therefore the demand for an increasing payload to basic mass ratio is still crucial. New strength and structural solutions allow a better utilisation of material properties which results in an optimized gross weight as well as in improved stability and reliability at the same time(2). Associating both statements one may presume that flight testing of an aeroplane verifies structure and mass design amongst many other features(3).

Indeed experimental verification of structural solutions is essential during the certification process in general. Therefore the quantities measured, the measurement method, its accuracy, explicitness and their mutuality during the experiment determine the final success. Concerning structure assessment an important group of parameters measured are deformations that provide information about the stiffness directly and about the stress state by using the constitutive model of the structure.

Deformations can be measured as:

- Displacement of certain points in defined directions;
- Displacement of the plane or surface;
- Strain in certain points or as a field of strain;
- Acceleration of certain points in defined directions.

Modern measurement techniques, the capability of gathering bulk data, transferring and processing on-line enable in-flight studies of phenomena or aircraft behaviours that were barely possible or strongly limited by weak hardware performance in former times. The stress state analysis under flight loads mentioned above is one example. The most common tool applied for many years have been strain gauges or accelerometers(4). The diagnostics of laminar composites introduced optical fibre gauges(5). Nevertheless none of these methods was able to identify extensive structural stress fields. This disadvantage could be overcome by the analysis methods based on digital image processing. Industrial applications of 3D scanners for surface shape or deformation measurements became a useful and popular tool also especially for quasi-static investigations. As one of the first attempts of in-flight application may be considered a method called Image Pattern Correlation Technique (IPCT), introduced by Klinge et al.(6, 7) of DLR Germany.

IPCT is an optical, non-intrusive measurement technique based on photogrammetry in combination with modern correlation algorithms developed for the Particle Image Velocimetry (PIV). The simplest IPCT set-up consists of one monochrome camera observing an object covered with a random dot pattern. Using image pairs of the randomly patterned object acquired by a stereoscopic camera system, its 3D position and shape can directly be measured. The significant advantages of the stereoscopic approach are that the 3D position can directly be triangulated (no constraints and models are needed) and the images of both cameras taken at the same instant of time are dewarped and correlated. Thus, a rotation of the pattern (e.g. caused by aileron deflection) will not cause any problem because the pattern has the same orientation in both images. An Example of two installations for different wing areas of a large airliner is shown in Figure 1 [(8)].

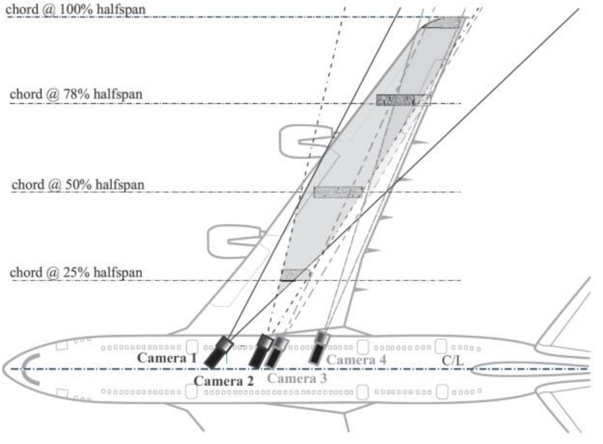

Figure 1. Application example of two stereoscopic IPCT camera sets placed in the fuselage of a large airliner for wing deformation measurements

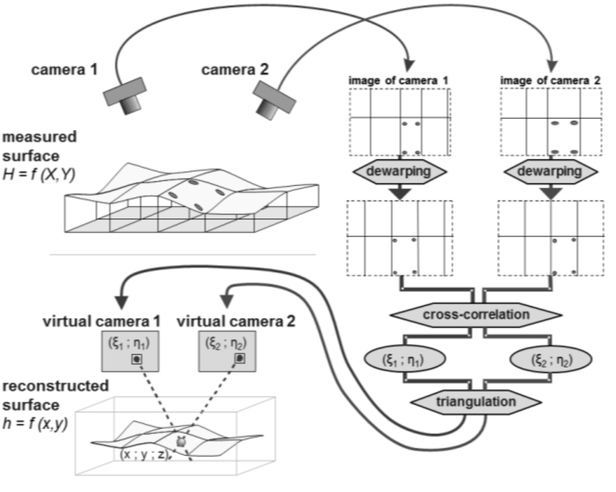

Figure 2. IPCT processing flow

The functionality of the stereoscopic IPCT approach for 3D surface shape registration is shown in Figure 2. The surface to be investigated with a random dot pattern is recorded by two cameras at the same instant of time. Both cameras cover at best a congruent area of interest with similar fields of view but under a different viewing angle. The images of both cameras are dewarped in a way that both cameras seem to look from the same point of view. Then a cross correlation algorithm identifies the image coordinates of areas with matching dot pattern in the images of camera 1 (coordinates x_1, y_1) and camera 2 (coordinates x_2, y_2). With known intrinsic parameters (e.g. focal length, distortion, principal point) and extrinsic parameters (position and orientation) of both cameras the real 3D coordinates of the processed dot pattern area are determined by means of central projection and triangulation. Applying this procedure to all pattern sections in the stereo image pair

depicting the same dot pattern region on the surface finally yields to a highly accurate reconstruction of the complete observed 3D surface.
Structure deformation is calculated using the IPCT tool in two subsequent time steps as described above. The deformation form is obtained by comparing the digital surface of the deformed state to a reference state (undeformed or not). Examplary measurement results of the wing deformation for the application illustrated in Figure 1 is presented in Figure 3.

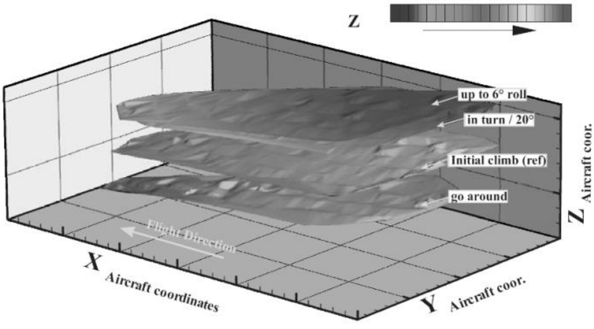

Figure 3. Wing tip displacement of a large airliner in different flight conditions

The development of IPCT with multiple application examples mainly took place within the framework of the two subsequent research projects co-funded by European Commission – Advanced In-Flight Measurement Techniques (AIM) and Advanced In-Flight Measurement Techniques 2 (AIM²) coordinated by the German Aerospace Center DLR[9]. Before the first AIM project the method matured from laboratory to first ground and in-flight applications. Within the projects and several supplementary tasks the measurement scenarios covered topics such as wing and aileron deflection of a glider, a commuter class aircraft and large airliners, wing vibration and flutter, main rotor blade deformation of a helicopter and propeller blade deformation. During more than ten years of continuous progress an own software dedicated to the specific in-flight conditions has been developed covering also procedures for hardware selection (cameras, lenses, etc.), installation issues, digital marker and pattern design as well as investigations about illumination conditions. Finally, the IPCT measurement method has been proven to be an off-the-shelf ready tool for engineering purposes in an industrial environment.

One of the scientific tasks within AIM² was to create a feedback between real measured in-flight structure deformations of an aircraft and corresponding numerical stress and strain calculations received during the preliminary design phase. In the following step the necessity and usefulness of such feedback had to be assessed. In this certain research program the tools used for structure deformation measurements in flight conditions was the image based method of IPCT and for numerical structure design the finite element method (FEM) was used.
This paper presents the outcomes of a flight test campaign in AIM² concerning application of IPCT for wing deformation measurements on a composite training glider as a source of numerical data for FEM calculations. All previous IPCT flight tests were performed with motorized and more or less spacious aircraft providing additional power supply for experimental installations. Moreover the airworthiness of the vessels obeyed special regulations for prototypes making the certification easier in most cases. The main purpose of the glider testing presented in this contribution laid in proving IPCT under conditions

never tried before with limited space and power on an aircraft taken straight from the hangar. Furthermore the preparation of this experiment was supposed to be a representative example of an engineering application scenario.

The next paragraph describes the test aircraft and the measurement installation. The following one concentrates on the flight test campaign, the certification and operational issues. Several measurement examples are presented in chapter 4. The last chapters are focused on the future work and lessons learned from this research program.

2.0 PW-6U FLYING TEST BED

2.1 The airframe

Initially it was planned to use the research aircraft AOS-71 electric glider when the AIM^2 project proposal was submitted. This carbon-epoxy aircraft is a joint project of Rzeszów and Warsaw Universities of Technology. Moreover, the electric glider AOS-71 was intended to be used as a multipurpose flying test-bed because already in its original factory configuration it is equipped with special joints for external installations. Due to a continuously increasing delay in the AOS-71 program schedule, that possibly interferes the progress of the AIM^2 project, the test bed was replaced by the PW-6U two-seated training glider. This aircraft which is basically identical to the AOS-71 electric glider but unpowered was designed as flying test-bed as well and is equipped with special joints for additional external installations.
The research glider PW-6U was modified to carry additional equipment for measurement and recording. The cameras for IPCT imaging, for example, were elevated over the centre line of the fuselage and installed in a specially designed housing attached to the fuselage by a vertical pod, as presented in Figure 4 (right).

Figure 4. Electric glider AOS-71 (left) and finally used unpowered glider PW-6U with dorsal camera pod (right)

2.2 IPCT measurement installation

Aiming for a global wing deformation measurement to match and compare the results with FEM calculations, a stereoscopic IPCT installation was chosen. Special boundary conditions linked to the use of a glider as a test bed strongly influenced the IPCT setup design in terms of miniaturization, simplicity and power management.

A digital mock-up (DMU) and accuracy estimations according to Kraus[10] were used for a virtual predefinition of all relevant camera system parameters such as type, lenses, position and alignment. Therefore boundaries like physical aptitude, availability and structural limits had to be taken into account. Also the random dot pattern was designed virtually using the DMU model. Before printing, the measurement setup was tested in virtual reality[11]. All relevant design parameters of the PW-6U IPCT installation are presented in Table 1.

Table 1
Feature summary of the stereoscopic IPCT installation for the PW-6U glider

Field of view	1100 mm x 5500 mm
Object speed	Slow – static deformation measurement
Imaging	Internal trigger generator ➔ 14.5 frames per second
Illumination	natural
Camera resolution	1620 x 1220 pixels² (JAI/HS CV-A2)
Focal length	2x 12.5 mm
Distance to object	4400 mm
Designed accuracy	dz = 1.5…7 mm
max. deformation / movement	~ +1 m, -0.5 m

The image recording installation was placed in two locations inside the airframe. Both cameras were housed in a fairing on top of the pod derived from the geometry of the optical system defined by DMU studies. The camera control and recording computer and the separate power supply were attached to the wooden rig in the rear cabin with the pilot seat removed. Electric and data transfer wiring were passed inside the pod.
Measurement of structure deformation based on comparison of subsequent airframe positions requires dedicated surface preparation. This IPCT pattern consists of two components. There is the random dot matrix, defined by dot size and their perspective stretch factor as well as the distribution density. This dot pattern is supplemented with a grid of 20 to 50 checkerboard markers of which the grid and marker dimension properties have to be acquired. Figure 5 (left) shows the applied IPCT pattern on the port wing of the test bed. Despite the loss of extensive surface information the a marker grid could also be used as a stand-alone target method as it is well known for common 3D position detection.
The installation was supplied by a dedicated flight data recorder and remote control panel for the test pilot[12]. In Figure 5 (right) the cabin installation with control computer, power supply, flight data recorder and wiring is shown.

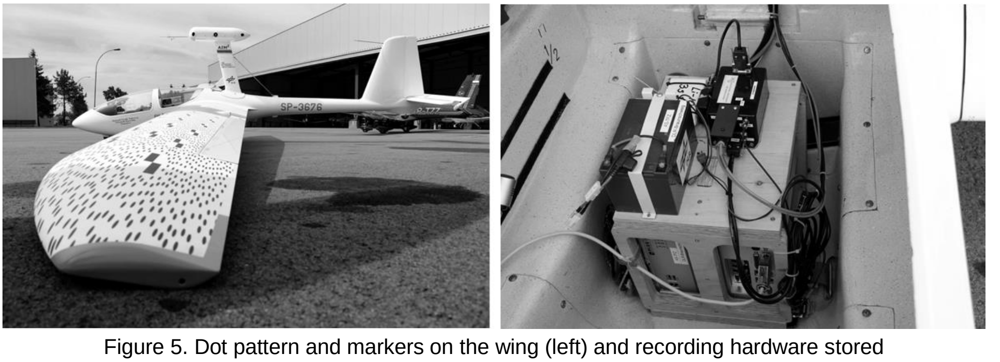

Figure 5. Dot pattern and markers on the wing (left) and recording hardware stored in the rear cabin (right)

3.0 FLIGHT TESTING – CERTIFICATION AND OPERATIONS

3.1 Initial preparations

Prior to the first flight test the modified glider underwent a series of ground tests to prove the reliability and strength of the proposed solution. Figure 6 depicts the test bed during a static (left) and a wind tunnel test (right).

The static ground test of the camera pod included five critical load cases identified as boundaries of the reduced flight envelope according to CS-22 requirements for gliders[(13)]. The main objective of the test was a deformation measurement of the pod structure and an overall reliability assessment. The results demonstrated that there were no significant or unexpected deformations. Moreover no damage to the structure was identified.

Aerodynamic ground tests were performed in the wind tunnel T-3 (∅5m) of the Institute of Aviation in Warsaw, Poland (ILOT). The main goals were to find force and moment changes on the glider fuselage and to quantify the influence of the pod on the directional stability. The fuselage with the pod had to stand a series of tests with different airflow velocities, angles of attack, angles of sideslip and rudder deflection angles. The range of the airflow velocity varied from 34 m/s to 40 m/s. All relevant forces and moments were recorded by a strain gauge based aerodynamic weighing device for five components. The angle of attack varied from α=-2° to +15° (1° step). During the tests no behaviour occurred that may disqualify the modified glider to be airworthy.

Before the first flight the ready equipped glider including the pod and all installations on-board was submitted to several ground rolls towed by a car up to lift-off speed.

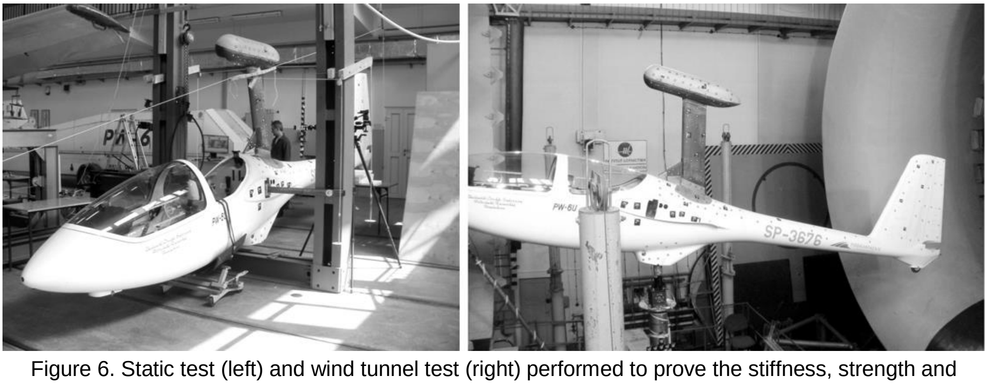

Figure 6. Static test (left) and wind tunnel test (right) performed to prove the stiffness, strength and stability of the camera pod

3.2 Airworthiness

The PW-6U glider type designated as a test bed belongs to an organisation that performs certified training. The type certificate is recognized by the Polish national aviation authorities under local regulations. Although the structure has been produced according to the prototype documentation with all additional reinforcement for external installations the scope of an Airworthiness Certificate (ARC) does not allow using them without permission. Therefore the glider was temporarily moved to the category *Specjalny* (this means “special” in Polish, a category for the aircraft with no type certificate, maintained by the owner only which is very common for rare or vintage models). Since then all modifications were allowed and supervised by a local authority inspector. What is more the category change process turned out to be reversible. With minor structure repairs the glider regained its initial type certificate after the flight test campaign. So far this is the only known certificate recovery in Poland because usually a type certificate once lost is irrecoverable.

3.3 Crew requirements

The selection of an appropriate and approved test pilot was one of the most time-consuming issues during this presented research program and caused almost two years of delay in the project schedule. In total three fatalities happened which were not directly connected with the project.
During the project duration European countries which are members of EASA were working on a transition of requirements in the field of flight crew licensing. The final date of this PART-FCL implementation in Poland was fixed to April, 8th 2014 which became vital for the successful project finalization. Prior to this date all flights planned in the project could only be performed by a glider test pilot.
All preparations for flight testing including the proof of airworthiness, the authorization of the test program and the crew selection were accomplished by May-June 2013. Unfortunately, the test pilot dedicated to this campaign died in a fatal accident while testing another airplane in mid of June 2013. A subsequent test pilot was engaged in the AIM^2 project for PW-6U testing. First assessment flights were scheduled for mid-August 2013. Two days before the planned first flight another PW-6 glider crashed, killing a student and seriously injuring an instructor. The authority immediately grounded all gliders of this type and demanded special mandatory maintenance of the empennage which was suspected to be the reason for the crash. Hence, the completely ready flight test installation had to be refurbished, the glider was sent to the producer and all test activities had to be postponed until 2014. In between, the actual AIM^2 PW-6U test pilot died in a fatal crash with another glider in November 2013.
Urgently, a new qualified test pilot had to be found during wintertime. Luckily the Polish authorities, introducing new licensing regulations, eased the respective pilot requirements in the meantime. According to the PART-FCL they approved an experienced glider flight instructor as a test pilot for the whole AIM^2 flight test program, except for the first flight. The latter had to be performed by a former glider test pilot.

3.4 Test flights

All flights were performed using the research aircraft PW-6U glider, reg. SP-3676 with the towing airplane Zlin Z-242L, reg. SP-TZZ. The pilot held a glider license with instructor rating and had the required experience on the PW-6 type. The first two certification flights were carried out by a glider test pilot. All flights took place on the EPRJ airfield with asphalt runway within the controlled airspace of the EPRZ international airport.
The test program included several tasks such as checks of the flight data recorder system, deformation measurements in sustained gliding flight, deformation measurements in sustained symmetrical manoeuvres and deformation measurements in turns. The complete log-book is presented in Table 2.

Table 2
IPCT test flight log-book

time	Flight no	Measurement
00:42	nr 01; 1st	**Certification flight**
00:37	nr 02; 2nd	**Certification flight**
Wing deformation measurement in sustained turn with various bank and in symmetrical manoeuvre.		
00:22	nr 05; 1st	4 measurement sequences in sustained gliding IAS=100 km/h and loop entries IAS=140 km/h. Shutter freq 12 Hz
00:37	nr 06; 2nd	3 measurement sequences in sustained gliding IAS=80, 90, 110 km/h. 3 loop entries IAS=130, 165, 170 km/h. 7 sustained turns with various bank. 2 sustained gliding IAS 90, 120 km/h. Shutter freq 12 Hz.
00:32	nr 09; 2nd	Flight program performed on July, 9^{th} was repeated. 11 sequences with shutter freq 14Hz.
00:42	nr 11; 4th	System malfunction. No data registered.
00:47	nr 12; 1st	33 measurement sequences. 15 trials in towing flight IAS in range 90 -160 km/h. 18 trials of loop entry with load factor n_z increasing up to 2.5. Shutter freq 14Hz.

4.0 RESULTS AND DISCUSSION

Having a look to the raw data of the IPCT image recording reveals a promising foundation of all together about 75 gigabyte of high quality stereo images. A good congruence between virtually designed and the real field of view of the cameras indicates the sophistication of the holistic setup design process using the experience gained during former IPCT application scenarios (IPCT pattern visible in the left part of Figure 7 not in final position).

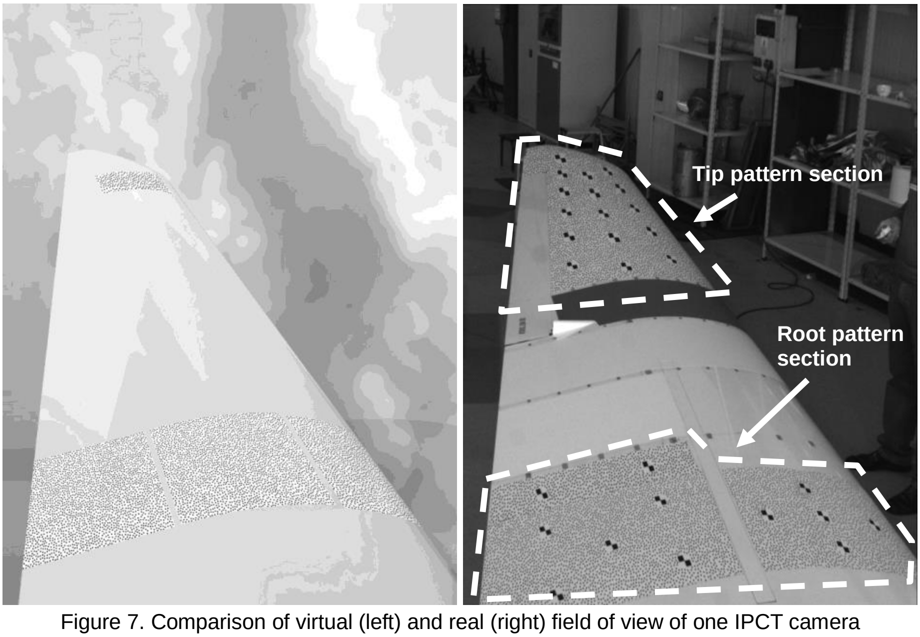

Figure 7. Comparison of virtual (left) and real (right) field of view of one IPCT camera

Also the images recorded in flight are of good quality in terms of illumination, pattern reflectance and contrast which is a vital requirement for a reliable IPCT evaluation. Only areas in the field of view of the cameras can be processed that are:

- prepared with the IPCT dot/marker pattern and
- recorded by both cameras at the same instant of time.

That is why all other parts of the image are masked out to ease the multi-pass mapping strategy implemented to the IPCT cross correlation software.

For time synchronization purposes with parameters of the flight data recorder each image pair is logged with GPS information such as time stamp and position. This enables a dedicated data processing of single or a series of interesting manoeuvres.

First of all the applied grid of integrated checkerboard markers is evaluated using a special edge detection algorithm which provides first local surface information and is used as starting point for further evaluation steps. This advances the processing of the dot pattern remarkably. In order to match the IPCT data with FEM calculations all evaluation results are transformed to a Cartesian wing coordinate system which has its origin at the leading edge 10 mm off the root connection to the fuselage (i.e. no standard aircraft coordinate system).

During the design phase of the IPCT setup the installation parameters were balanced between structural constraints and accuracy requirements. Figure 8 (left) shows the estimated measurement error according to Kraus[(10)] for the stereoscopic setup with a varying base distance (sensor camera 1 to sensor camera 2). Considering this the stereoscopic base width was set to one meter with an expected accuracy of the system between 1.5 mm near the cameras up to 7 mm at the wing tip (see also Table 1). For the real measurement it is not easy to determine error values but a good indication for at least the systematic error part provides the averaging of a number of static on-ground recording results. This has been done for 100 samples and is illustrated in Figure 8 (right). A partitioning reference into root and tip section is given in Figure 7 (right).

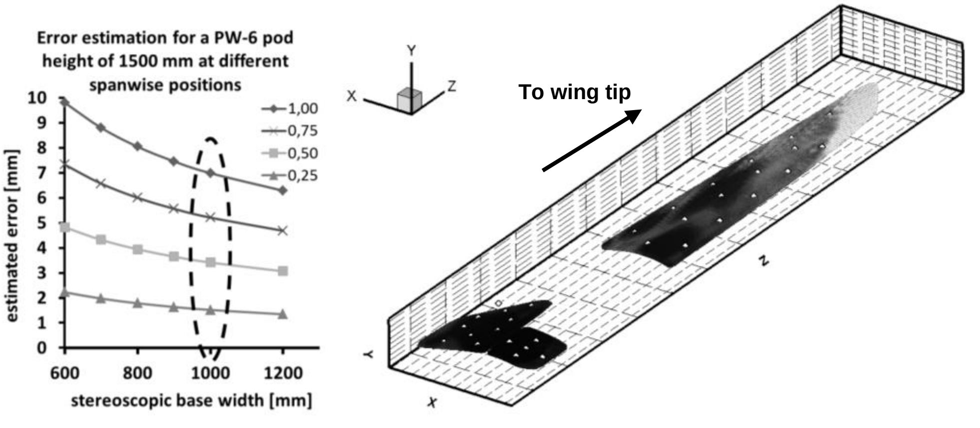

Figure 8. Theoretical error estimation in spanwise direction for different distances between two cameras (left); processed ground shape recording of the port wing overlaid with a greyscale code for standard deviation of 100 averaged IPCT image pairs; the darker the better (right)

The greyscale in the right part of Figure 8 pertains to the standard deviation (STD) of 100 averaged image pairs that were recorded in a levelled static on-ground condition as a reference during the calibration procedure. Darker areas in the root section represent STD values better than 0.5 mm whereas higher STD values towards the wing tip rise up to approx. 5 mm at most and appear in lighter grey nuances. So, the error values for this measurement are within the theoretically estimated range and testify reliable IPCT results.

In Figure 9 an exemplary IPCT result is presented. The depiction shows the wing shape of the glider for two different load cases measured with IPCT. A wing deformation of about 360 mm at the wing tip was determined comparing the reference on-ground shape (dark with white marker positions, see also Figure 8) with the wing shape during a manoeuvre with a constant vertical acceleration of approx. 1.8*g* (light with black marker positions). Regarding the measured deformation magnitude of several hundred millimetres leads to a relative accuracy of better than 2%.

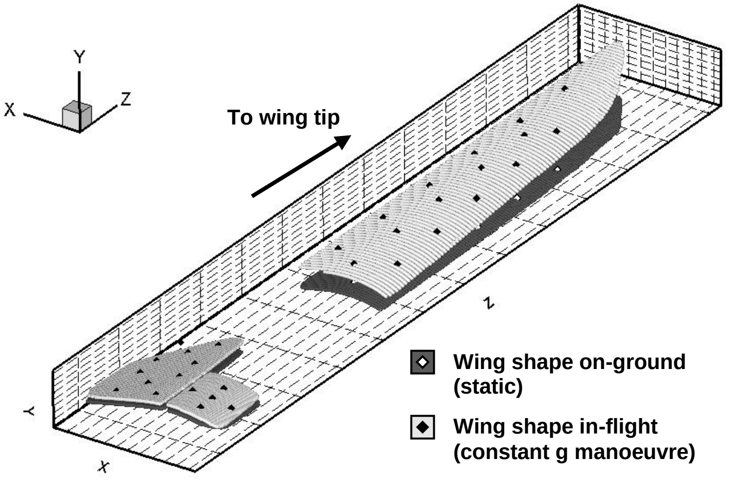

Figure 9. Representative IPCT result comparing the shape of the port wing on-ground (dark with white marker positions) with the wing shape during a manoeuvre with constant vertical acceleration (light with black marker positions)

Further post-processing steps are firstly a projection of the in-flight measurement results to the reference ground shape to calculate a comprehensive deformation distribution. Secondly, a transfer of these effective deformation data to a meshed FEM node grid links the IPCT measurement results with the respective numerical FEM model of the glider wing.

The scientific flight test campaign presented in this paper was focused on the assessment of a new application scenario for the deformation measurement method IPCT. In order to realize this project several challenges were successfully taken. On the one hand a class of aircraft like the composite training glider PW-6U had not been examined with IPCT before and this type of aircraft initially was not dedicated to research. Also the major part of the researchers had to be trained as the team had had no experience with the measurement method. The results of the PW-6U test campaign proved the reliable applicability of IPCT for test beds of this category.

5.0 POTENTIAL FOR FURTHER WORK

The present and preceding research projects aiming at in-flight displacement and deformation measurements using the modern method IPCT proved its reliability and feasibility for industrial applications. Now, further fields of application using the miniaturized IPCT setup can be covered where the control computer has to be small, energy saving and can be autonomously powered with a separate battery. Further development potential lies in two branches of IPCT. On the one hand the miniaturized system could be adapted to cameras with better performance in terms of resolution, frame rate, sensor sensitivity and image quality in general. On the other hand the robust post-processing algorithms can be enhanced which work reliably but relatively slow and do not include timeline correlation yet.

This particular measurements on a glider provided wing deformation data for further analysis of the composite structure. The authors proposed an advanced approach for aircraft structure analysis by combining optical deformation measurement data gathered in-flight with a numerical FEM model.

The algorithm of data transfer between the IPCT post-processing software and the Finite Element Method pre-processor enabled to associate a 3D IPCT result with the nodes of a corresponding finite element mesh. Therefore, the stress or strain distribution in the structure as a result of initial deformation corresponds to the in-flight conditions. The detailed description of this procedure will be addressed in subsequent publications.

6.0 LESSONS LEARNED

Despite being another one in their research history, the flight test campaign presented in this paper was a challenging task for both partners the Rzeszów University of Technology and the German Aerospace Center DLR. The experience gained during this collaborative research program allowed to identify issues, procedures or other relevant events that should be taken into account for following activities of this type. Both, the positive achievements as well as threats or inconveniences became vital lessons for the team, worth to be mentioned for the respective research community. The most numerous remarks concern the preliminary preparations and operational matters. Some of them are connected to the flying test bed itself. The following conclusions of this project are sorted into three categories:
⇑ as worth to be repeated in further campaigns, ⇔ as might be considered in scope of precaution or doubt and ⇓ as threats or issues that should be avoided.

⇑ A **Significant distance between partner sites** and a limited number of bilateral meetings had no influence on the project performance. Electronic media allowed to transfer bulk data and to communicate in real time without delay. Furthermore, these factors disciplined the team members to do dependable preparations and work time-effective;

⇑ The **flight trials were located in a C-class controlled airspace** of an international airport with traffic of mid density. Proper pre-planning with air traffic controllers and coordination of research sorties with scheduled and unscheduled flights prevented delays within the program.

- ⇔ The **airfield** of the Rzeszów University of Technology **has an asphalt runway with taxiways, aprons and hangars**. Usually gliders operate from small grass airfields. In contrast to that research flights with tiny and sensitive metrology installations demand a convenient environment with maintenance hangar and hardened pavements. Therefore, the number of possible locations might be limited significantly.

- ⇔ A **towing airplane** is inevitable for glider flight testing.

- ⇔ A **chase airplane** might be considered as an additional element of the recording system but here it was used for observation and photo documentation matters only.

- ⇓ The **work load, number of required crew members and individual effort** for flight testing with a glider is relatively high compared to the reduced complexity of a glider itself. Campaigns with powered aircraft seem to be easier to coordinate and perform.

- ⇓ The **flying test bed** should be chosen carefully. Planning a program with a not yet ready prototype is risky and may cause unexpected delays or cancellations.

- ⇓ **Changes in certification and licensing requirements** always generate irritating delays, especially when authorities do not have respective procedures. In this program only the interpretation for an approved pilot took half a year.

7.0 CONCLUSIONS

This paper presents an exemplary industrial application of a promising optical metrology. The typical task of experimental verification of the structure stiffness and strength has been solved. Using the digital image correlation method IPCT the wing structure deformation was measured. Therefore, the following summary of this flight test campaign can be stated:

- The design and preparation of the measurement setup for the composite glider were based on solutions and procedures elaborated according to experience gained during previous measurement campaigns. Despite the aircraft might be considered as generally not dedicated to flight testing no unexpected technical difficulties were encountered during the task.
- The hardware and software for data pre- and post-processing might be considered as ready off-the-shelf.

Concerning the previous statements this example proves that stereoscopic IPCT has been developed to the level of research applications in an industrial environment as it was considered at the beginning of the AIM² project.
The results of the measurements in flight conditions allowed preparing essential data for further investigations of numerical airframe structure models.
Nevertheless, some lessons learned should be kept in mind:

- The most difficulties which were generating delays in the program schedule resulted from official requirements demanded by aviation authority concerning examination of the test bed reliability and durability. Furthermore, the official requirements for the flight and ground personnel should be figured out well before.

- Also the change of the test platform from the not-ready prototype to a series aircraft took one year.

The effective amount of time for preparation and testing turned out to be relatively small but it was multiplied by certification issues.

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